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INTEGRATION OF MODAL VEHICLE EMISSION MODELS WITH THE TRANSIMS TRAFFIC SIMULATION MODULE

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Background

TRANSIMS is a set of integrated analytical and simulation models and supporting data bases. The TRANSIMS methods deal with individual behavioral units and proceed through several steps to estimate travel. TRANSIMS predicts trips for individual households, residents and vehicles rather than for zonal aggregations of households. TRANSIMS also predicts the movement of individual freight loads. A regional microsimulation executes the generated trips on the transportation network, modeling the individual vehicle interactions and predicting the transportation system performance.

The purpose of the TRANSIMS environmental module is to translate traveler behavior into consequent air quality, energy consumption, and carbon dioxide emissions. There are four major tasks required to translate traveler behavior into environmental consequences: (1) estimate the emissions, (2) describe the atmospheric conditions into which the contaminants are emitted, (3) describe the local transport and dispersion, and (4) describe the chemical reactions that occur during transport and dispersion of the contaminants

TRANSIMS is designed to simulate the total traffic in a metropolitan area not only on freeways and main arterials, but also on residential streets. This requires that that the traffic simulation be very computationally efficient. The traffic simulation method chosen to obtain the required computational speeds is a cellular automata (CA) microsimulation. The simulation locates vehicles with in the accuracy of 7.5 meters and uses only 6 speeds and 1 acceleration value to describe the motion of the vehicles. The modal emission models being developed now assume an input of a reasonably smooth trajectory and the output of the traffic microsimulation does not provide that. Also, the microsimulation output does not contain information about the different acceleration and declarations patterns of operating vehicles. Thus a method that provides information about real driving patterns must be developed to interface between the coarse microsimulation output and the modal emission models.

Traffic Microsimulation

The Travel Microsimulation module mimics the movement and interactions of travelers throughout a metropolitan region's transportation system. The approach is to use a cellular automata (CA) microsimulation. CA traffic models divide the transportation network into a finite number of cells. In the current form each cell's length is the average distance between vehicles when traffic is at a complete standstill (7.5 meters). A cell may be empty or contain a single vehicle. If it contains a vehicle, the vehicle has an integer velocity between zero and maximum velocity, Vmax=5. The integer velocity represents the number of cells that vehicle moves the next step. The step size is exactly one second, in which case Vmax corresponds to 135 km/hour, or about 84 mph. This step size abets fast computation because the updated vehicle position is computed by integer arithmetic and without multiplication of velocity and time step.

Updating the vehicle's next velocity and position is quite simple. First, we define the number of unoccupied cells ahead of the vehicle as its "gap". Then, we update the velocity by accelerating to the maximum velocity without running into the vehicle ahead:

$$V(t+1)=\min[V(t)+1, Vmax, gap].$$

But, with probability P, we reduce this tentative velocity by one (without going backwards):

$$V(t+1)=\max[V(t+1)-1,0].$$

Finally, we update the vehicle's position:

$$X(t+1)=X(t)+V(t+1).$$

This rule set is called the Nagel-Schreckenberg model. The random velocity reduction process captures driver behavior such as free-speed driving fluctuations, non-deterministic accelerations, and overreactions when braking. The simple one-lane model has been extended to cover lane changing, passing, merging, and turning behaviors.

The simple model produces dynamics observable in everyday freeway traffic. First, we can display an individual vehicle's movement in space and time as shown in Figure 1. Vehicles moving at constant velocity leave straight-line tracks slanting downward to the right. A stopped vehicle moves in time, but not in space, creating a vertical line. The figure shows the spontaneous formation of well-known traffic shock waves that propagate backward in space.

This model also produces the fundamental flow-density relationship shown in Figure 2 where density has been normalized to 1.0 for a completely jammed system. At low densities, flow increases linearly with more vehicles in the system. Near a density of 0.1 the system achieves maximum throughput or 'capacity,' but the flow is quite chaotic and its variability increases dramatically.

Although this coarse representation of vehicle motion captures the traffic characteristics with sufficient detail, the output of the traffic simulation is much to coarse to be used in generating vehicle emissions using existing modal emissions models. Figure 3 gives an example of this by showing the speed time trace that would be produced by the CA simulation for a vehicle accelerating to a velocity of ~75 mph and then driving at a steady speed of 75 mph.

Interface Methodology

One way of obtaining useful data from information like that presented in figure 3 would be to use a low pass filter on the data that would remove the abrupt speed changes. However such a filter would produce only an average acceleration profile and would not give the extremes in real-life acceleration patterns that produce effects such as enrichment.

We are developing an approach to produce realistic, smooth vehicle trajectories that can be used in the emissions module. The current interface prototype collects, over time, for each speed bin, the number of acceleration and deceleration events that occur in a particular spatial cell. Once the fraction of vehicles that are accelerating is known, the fraction with a specific acceleration is calculated by using conditional probabilities derived from EPA's three cities study (USEPA, 1993). The conditional probability of a particular acceleration in these data is a function of the speed times acceleration and is shown in Figure 4. For each vehicle accelerating from a particular speed bin we randomly select an acceleration using the distribution given in Figure 4. The result is a distribution of accelerations that occur for a particular spatial cell over a time interval. By finding this distribution for a number of adjacent cells we can develop a set of trajectories for the vehicles.

If only the six speed bins in the microsimulation are used as the vehicle speeds, this methodology still produces unrealistic acceleration and speed distributions. Therefore, the vehicle speeds are distributed evenly into 10 sub-bins for each CA speed bin. Also, the vehicles are assumed to be evenly distributed in the spatial cell.

With only the above methods, the acceleration value for each acceleration event is independent of the previous acceleration for the vehicle. Thus without further modifications no particular vehicle would consistently exhibit behavior that could be classified as aggressive. To provide the capability to identify aggressive drivers in the simulation, we grouped the Three Cities data into 8 levels of aggressiveness and then consistently selected a vehicle's accelerations from a specific level of aggressiveness. This created vehicle trajectories that included a consistent representation of various driver behavior. Because the trajectories still depend on random selection of accelerations the resulting trajectories are still noisy. Currently a Kalman filter is used to remove some of the noise from the acceleration and deceleration probabilities to produce smooth trajectories.

We have done some testing of the use of this method. We began with actual vehicle trajectories from a database developed by the California Air Resource Board (Effa and Larson, 1993). We overlaid a grid on the vehicle's trajectory and deduced equivalent CA positions and velocities. The trajectories were grouped into 10 sets; three sets of arterials, slow, medium, and fast, and 7 freeway sets ordered by increasing congestion. The most uncongested freeway set had average speeds of about 60 mph while the most congested set had average speeds of about 10 mph. In each case we used only the first 30 seconds of the driving. Therefore the output from the synthetic CA data consists of the fraction of the vehicles in each CA speed bin for each CA cell plus the fraction that increased CA speeds in a cell and the fraction that decreased speeds in a cell.

These data were then input into the interface approach to determine how accurately the approach could generate the distributions of speeds and accelerations that were existent in the original data. It should be noted that we were not trying to reproduce the trajectories of individual vehicles in the CARB, but the distribution of trajectories in the data. We then used the modal emissions model VESHIME (Carlson, et. al., 1994) to find the vehicle emission both from the original real data and the distributions obtained from the interface methodology, to provide a estimation of how well the method reproduced the emissions.

The averages of speeds, CO emissions, NOx emissions, hydrocarbon emissions, and fuel consumption for a collection of ~ 100 vehicles were compared to those from the original trajectories. Figure 5 reports such a comparison for CO emissions for a medium speed freeway link. Figure 6 reports such a comparison for NOx emissions for a medium speed freeway segment, while Figure 7 gives the comparison for hydrocarbon emissions on a medium speed freeway link. The average speeds on the medium speed freeway link are shown in Figure 8. Figures 9 through 12 show the comparisons for a very congested freeway link for CO, NOx, hydrocarbon emissions and average speeds respectively. Overall the comparisons show the need for further development, but they also show that the system can produce respectable results over a wide range of driving conditions.

Future Work

We are planning to continue to refine this interface methodology using additional data on driving behavior that had been and is being collected by other institutions. Specifically freeway entrance ramp driving behavior collected by California Polytechnical Institute (Sullivan and Chatziioanou, 1993) will be used to obtain speeds and accelerations on free way entrance ramps.

We are planning to begin tests using actual traffic simulation output and compare the resulting estimated emissions to the emissions calculated from the data collected in the various studies. Also we are planning to work on developing interface methodologies for modal emissions models other that VESHIME, specifically the models being developed by the University of California at Riverside and the University of Michigan (Goodwin and Ross, 1996)

Summary

The traffic simulation module of TRANSIMS produces a coarse estimate of actual driving behavior. We have developed a method to interface this information with modal emissions models that includes information about driver behavior collected in the Three Cities Study. The method was tested by determining if we could reproduce the vehicle trajectory distributions that occurred in driving behavior measurements made for CARB on actual roads. Comparisons of the calculated emissions using the real data and the distributions generated by the interface methodology have indicated that we are close to having an acceptable methodology for the interface.

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Effa, Robert C. and Lawrence C. Larson (1993), "Development of Real-World Driving Cycles for Estimating Facility-Specific Emissions from Light-Duty Vehicles," California Environmental Protection Agency - Air Resources Board - presented at the Air and Waste Management Association Specialty Conference on Emission Inventory, Pasadena, California

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Sullivan, Edward and Alypios Chatziioanou, (1993), "Vehicle Speeds and Accelerations Along On-Ramps: Inputs to Determine the Emissions Effects of Ramp Metering FINAL REPORT," Transportation Research Group, California Polytechnic State University, San Luis Obispo, CA

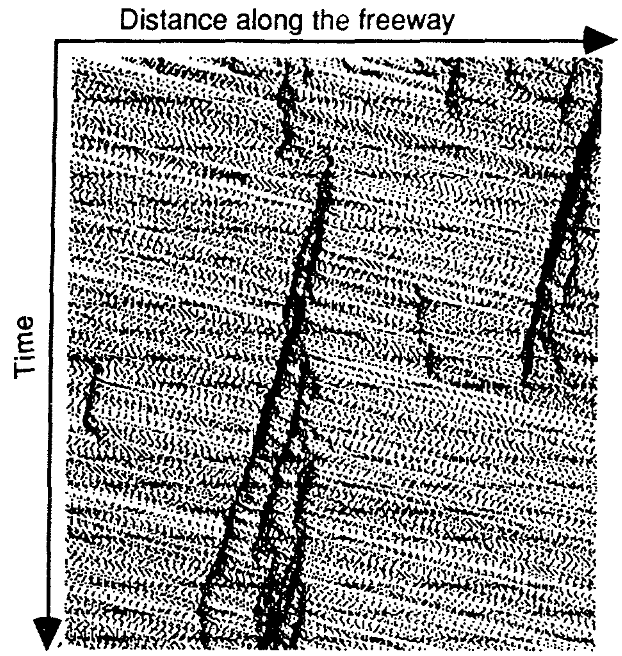

Figure 1. Waterfall plot of traffic dynamics produced by a cellular automata model.

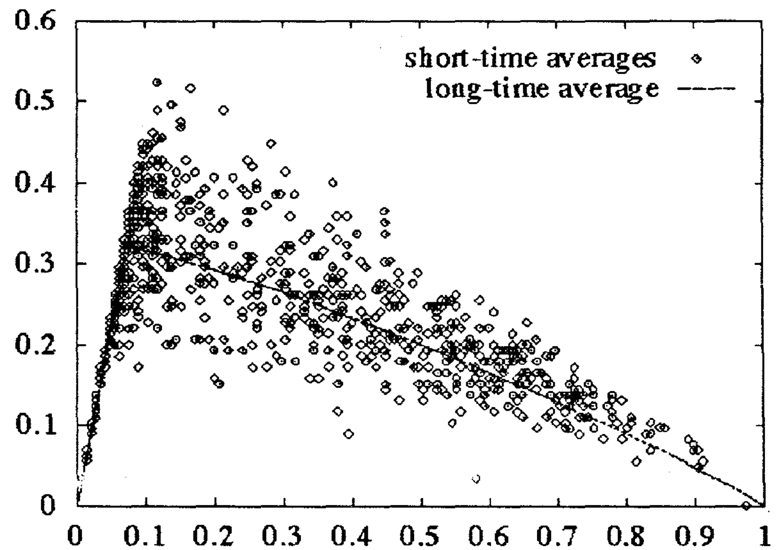

Figure 2. Fundamental flow-density relationships produced by a cellular automata model.

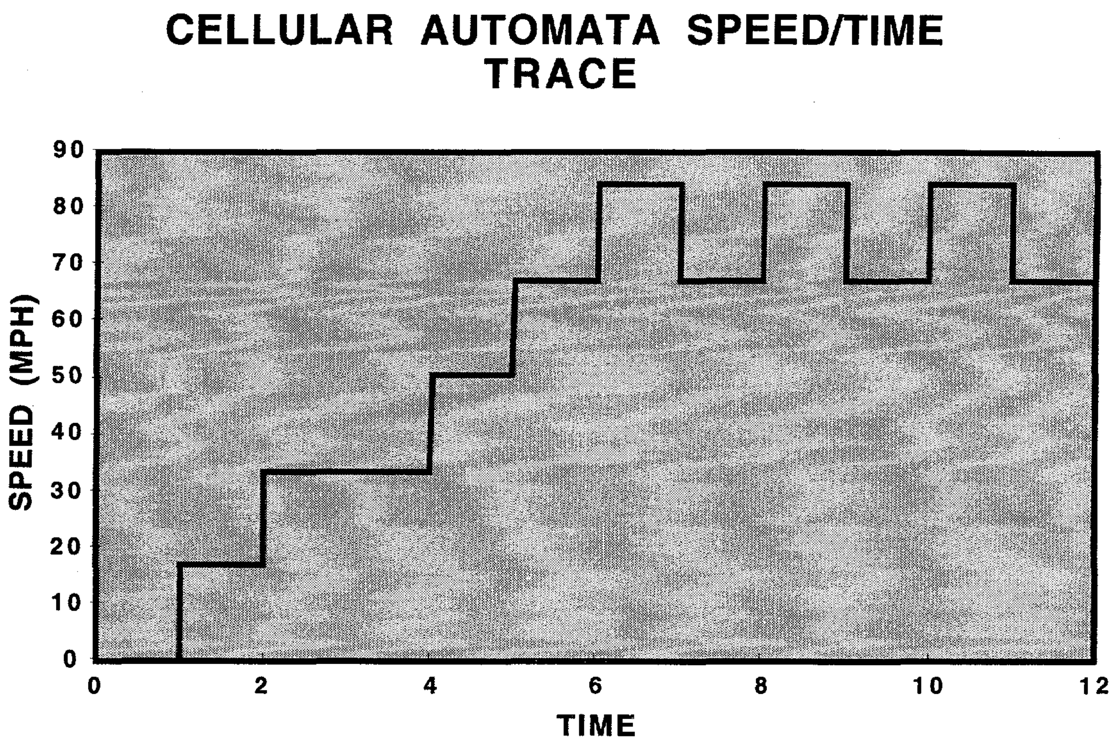

Figure 3. An example of a Speed-Time trace produced for an accelerating vehicle by a cellular automata model.

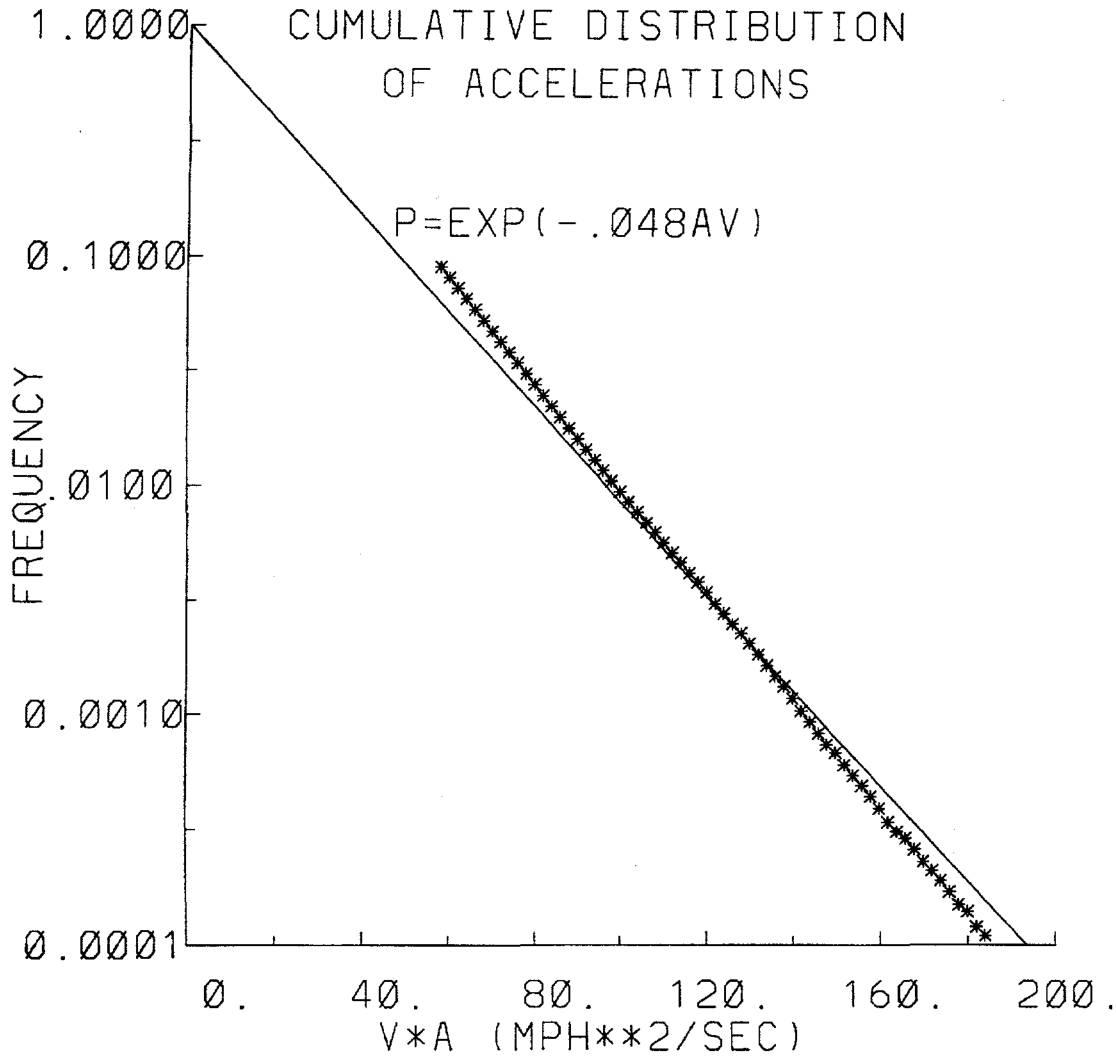

Figure 4. The cumulative probability distribution used to select accelerations values for different speed bins.

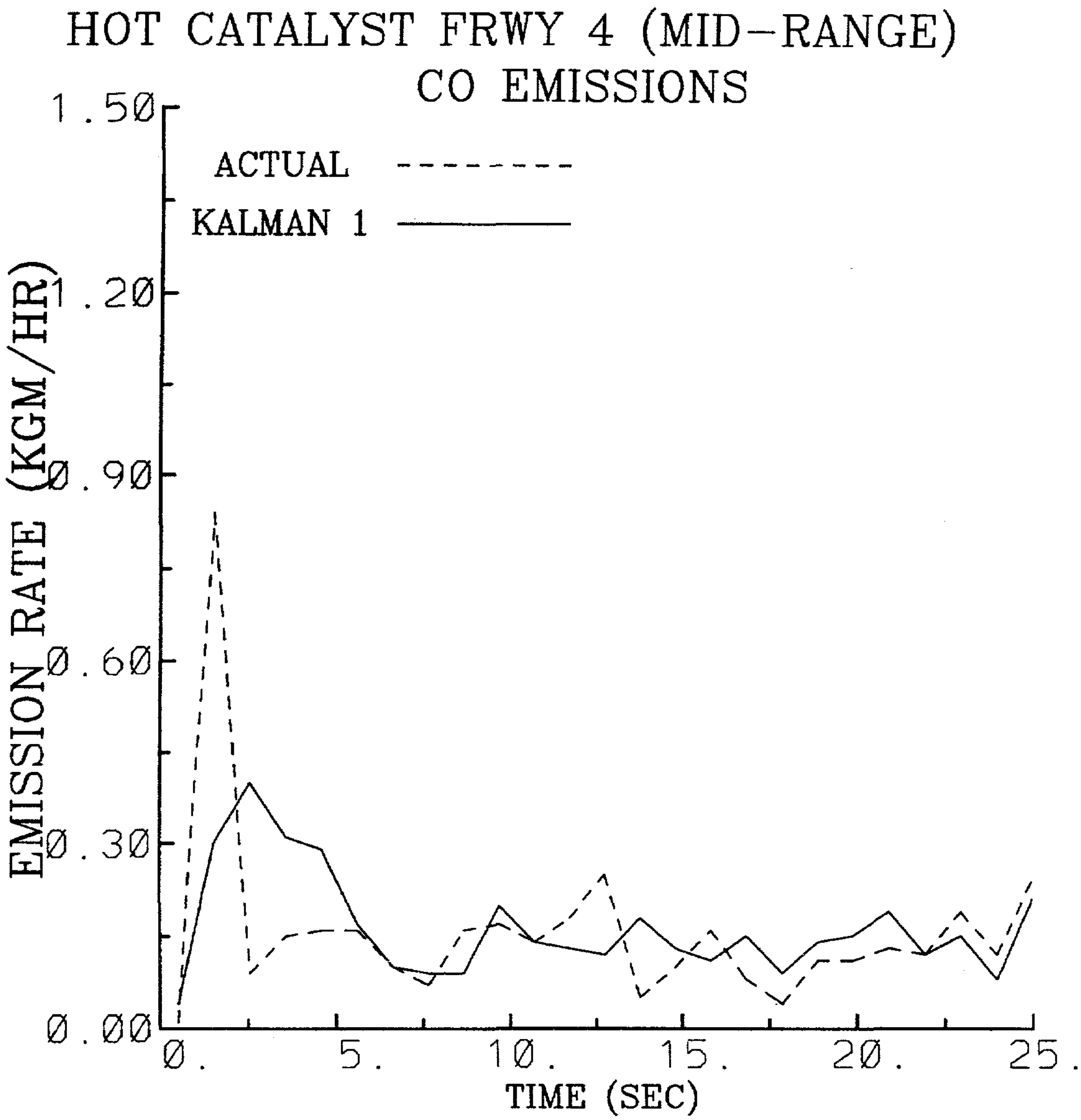

Figure 5. Comparison between average CO emissions estimated from VESHIME with real driving on a moderately congested freeway link and those produced from synthetic CA data on the same link.

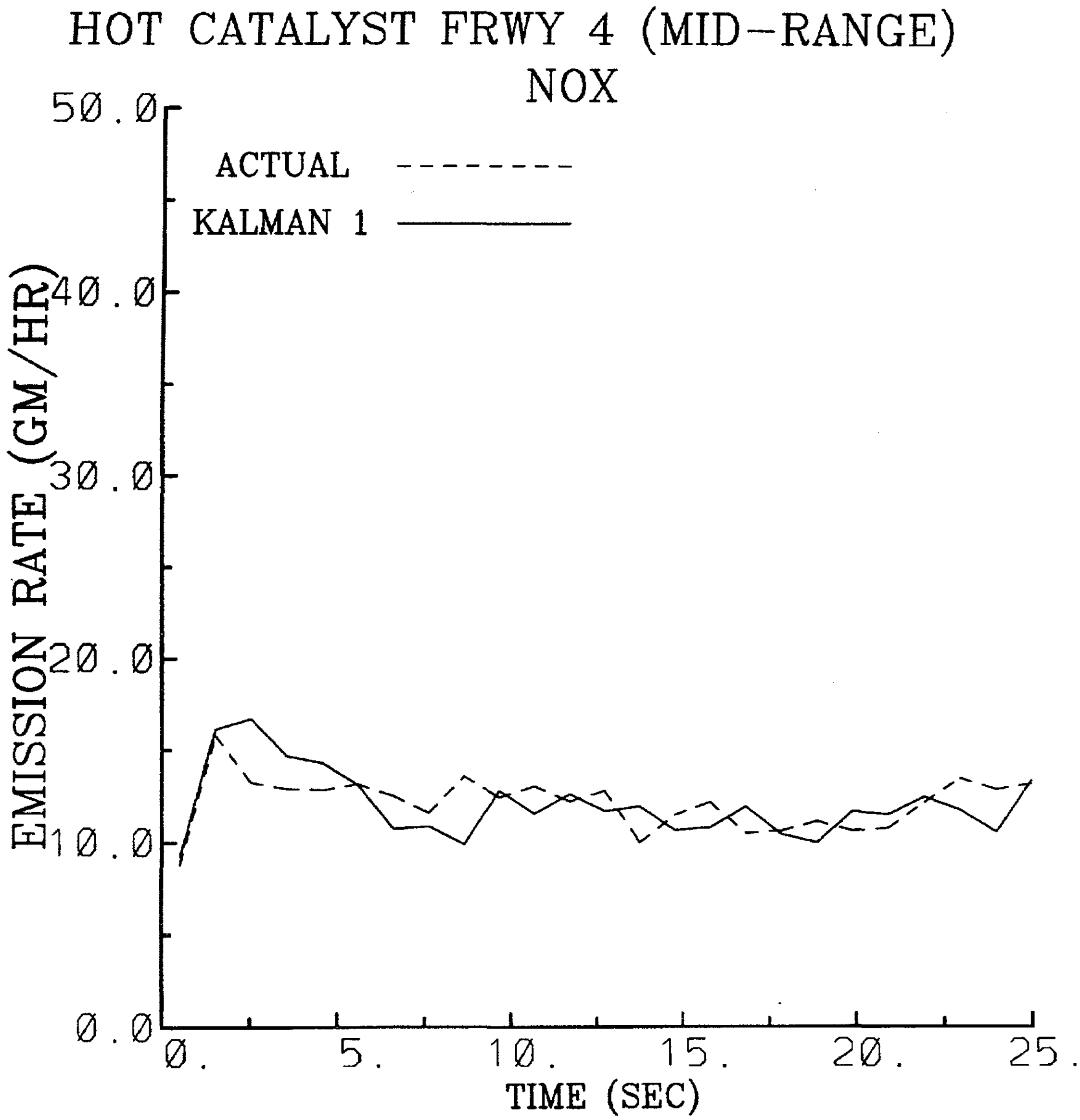

Figure 6. Comparison between average NOx emissions estimated from VESHIME with real driving on a moderately congested freeway link and those produced from synthetic CA data on the same link.

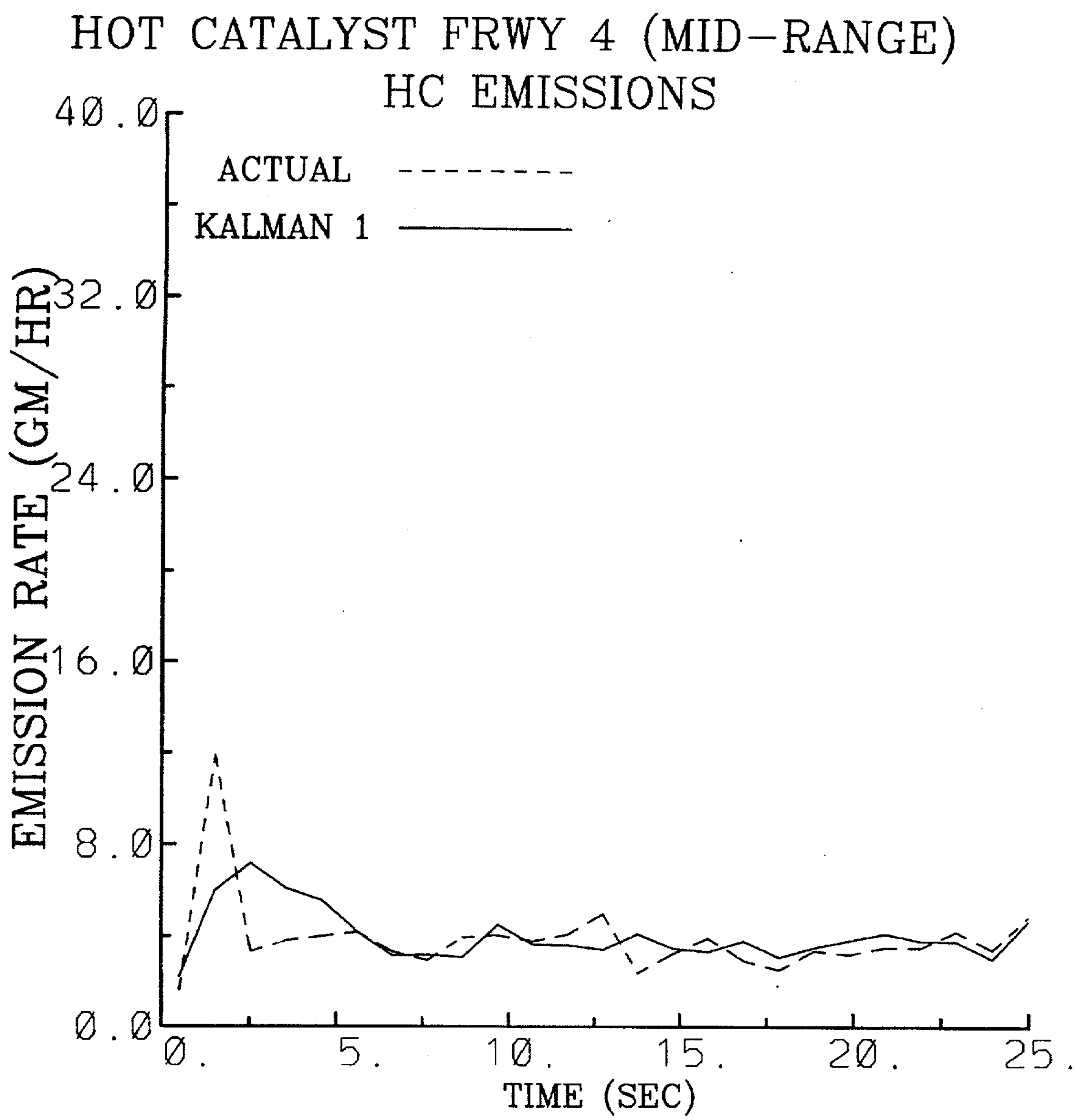

Figure 7. Comparison between average hydrocarbon emissions estimated from VEHSIME with real driving on a moderately congested freeway link and those produced from synthetic CA data on the same link.

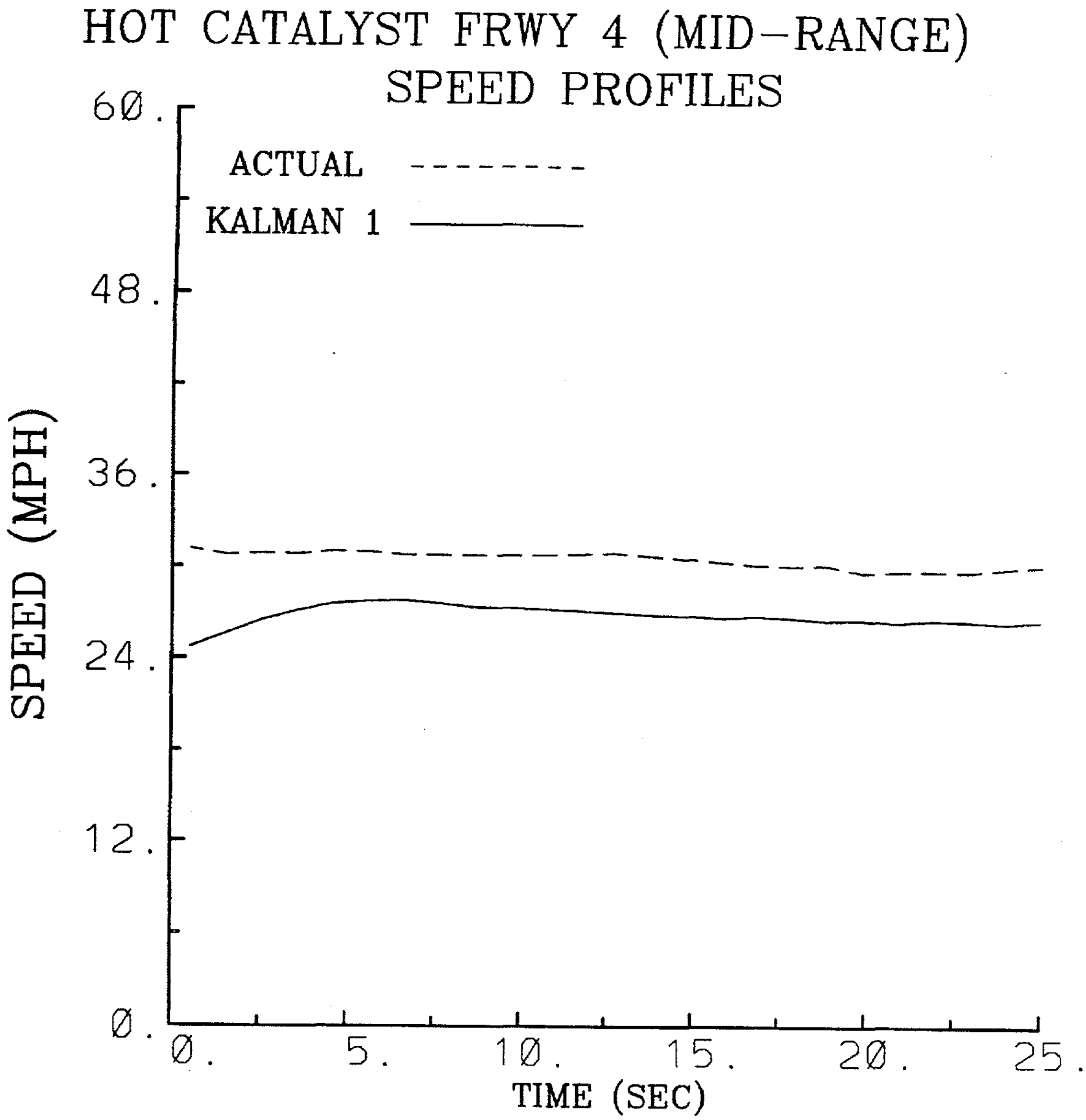

Figure 8. Comparison between average speeds with real driving on a moderately congested freeway link and those produced from synthetic CA data on the same link.

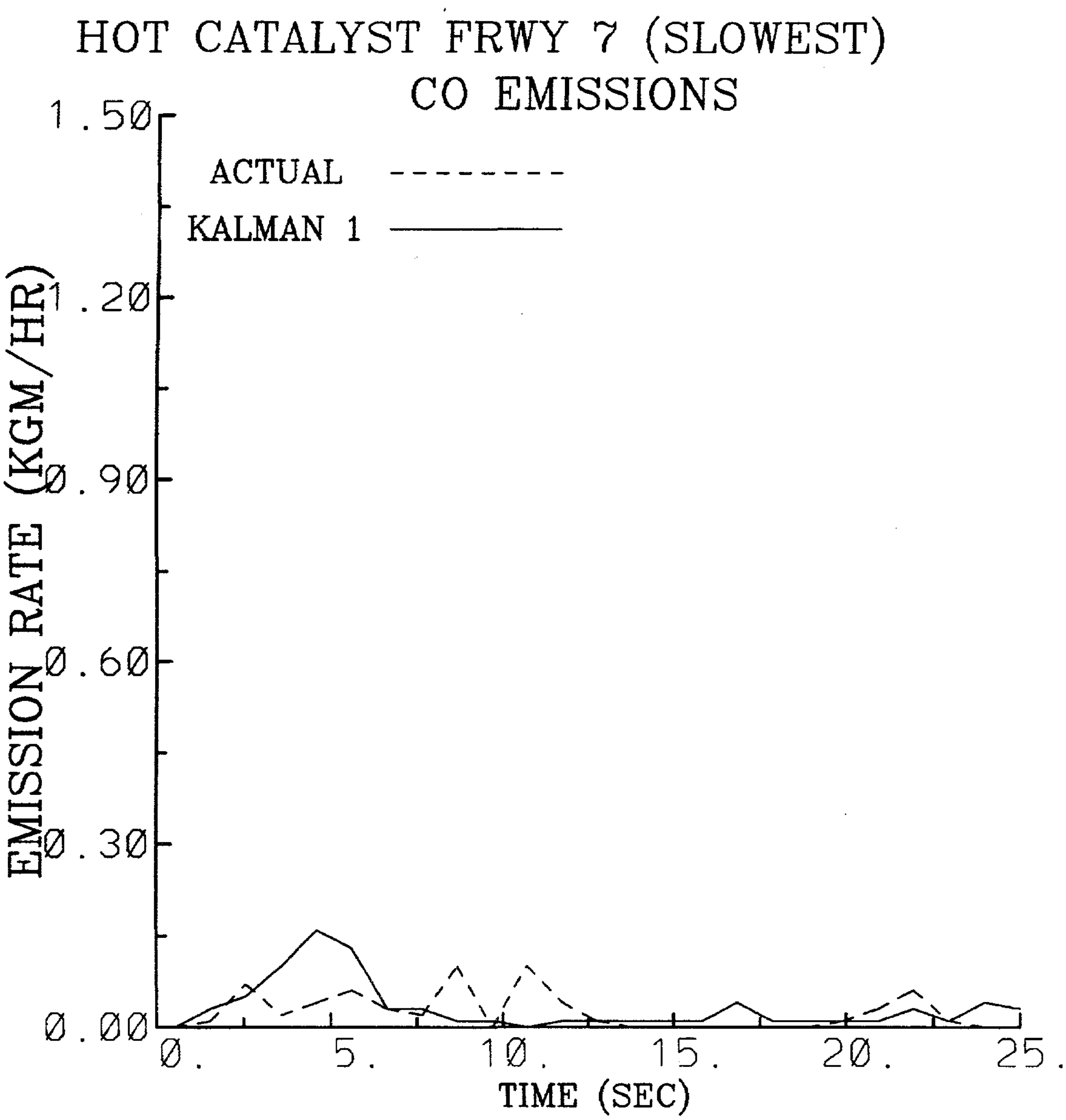

Figure 9. Comparison between average CO emissions estimated from VEHSIME with real driving data on a very congested freeway link and those produced from synthetic CA data on the same link.

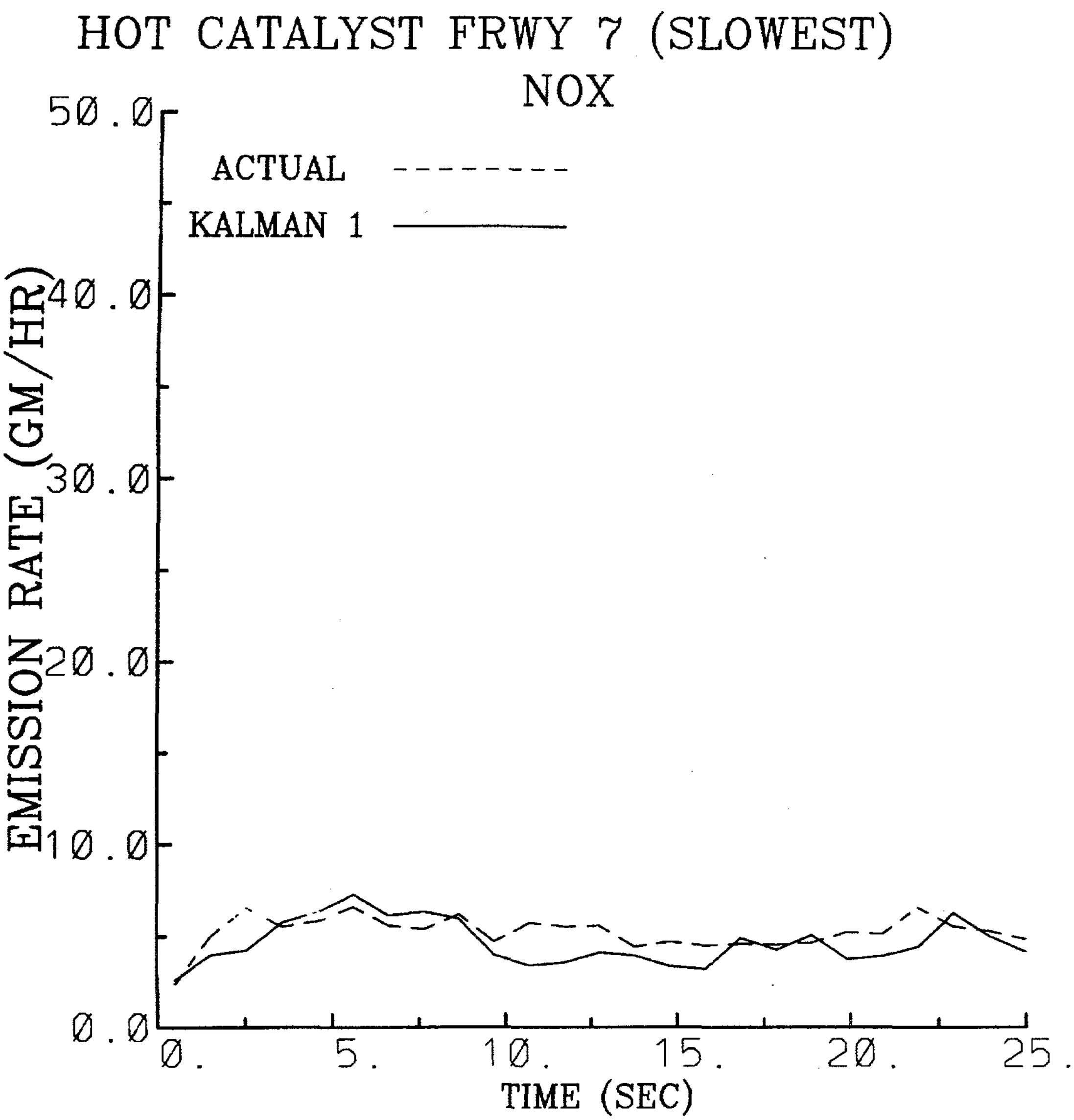

Figure 10. Comparison between average NOx emissions estimated from VEHSIME with real driving on a very congested freeway link and those produced from synthetic CA data on the same link.

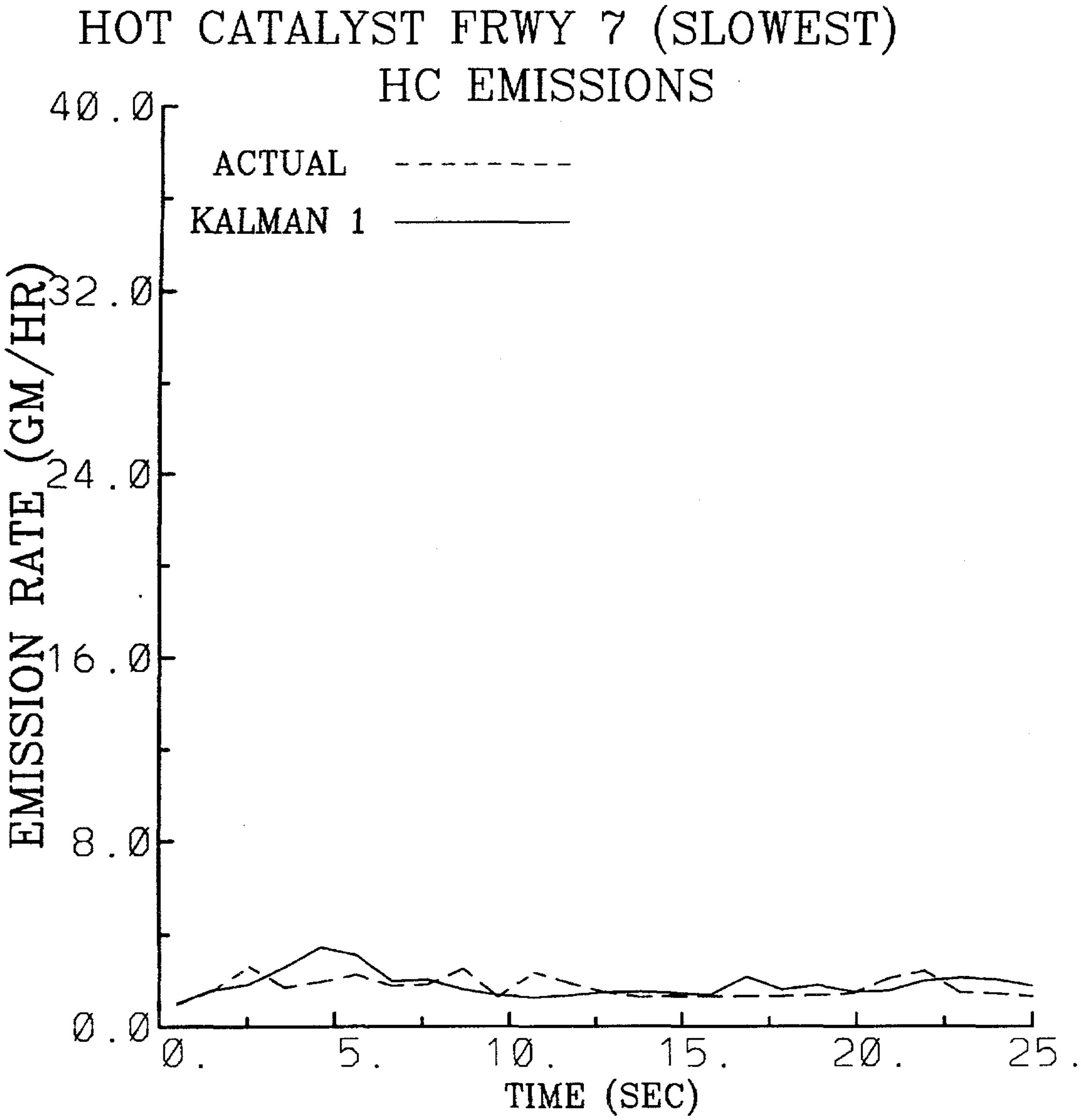

Figure 11. Comparison between average hydrocarbon emissions estimated from VEHSIME with real driving on a very congested freeway link and those produced from synthetic CA data on the same link.

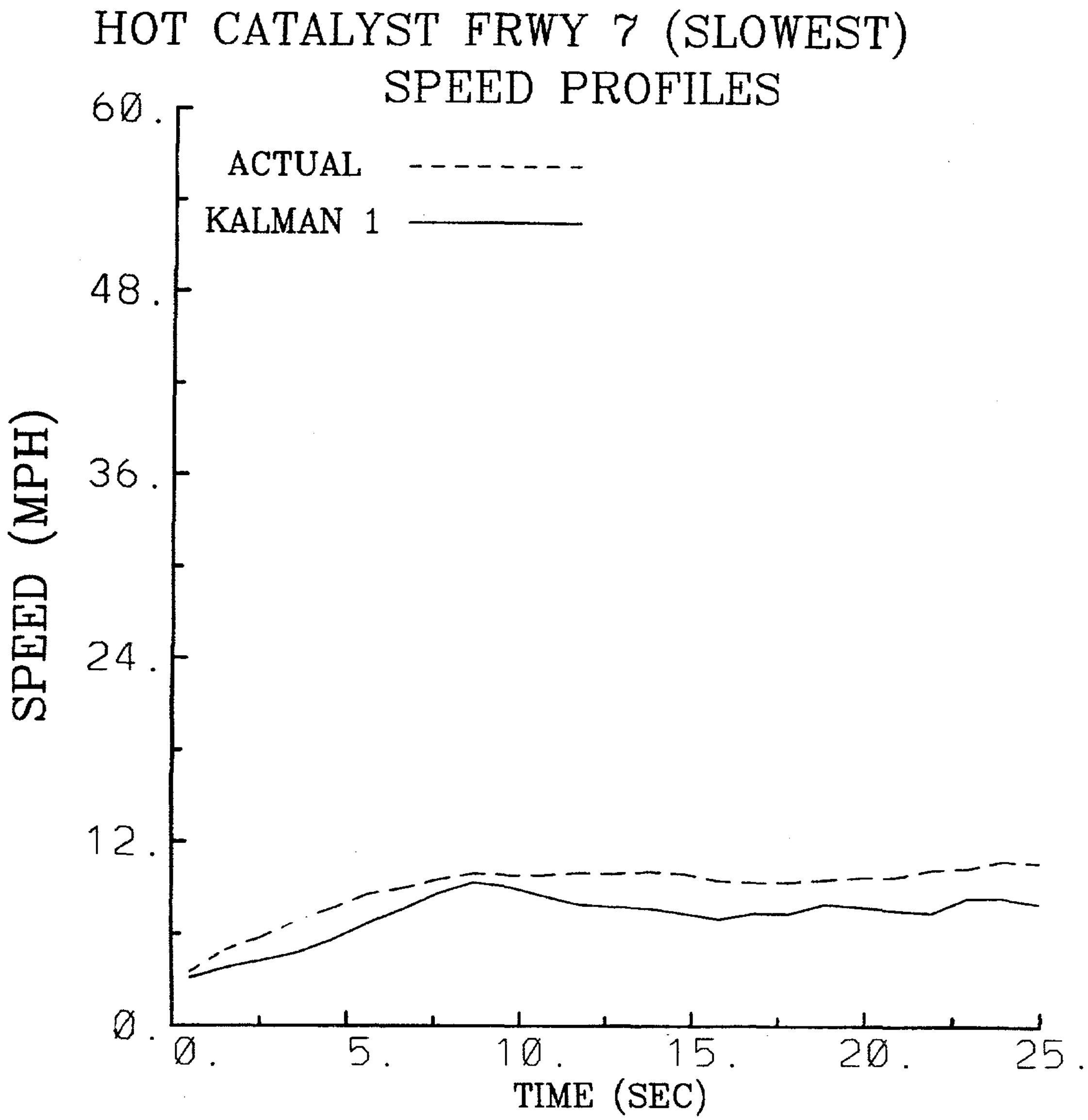

Figure 12. Comparison between average speeds with real driving on a very congested freeway link and those produced from synthetic CA data on the same link.